Chapter 10

Paediatric Amplification: Non-Implantable Devices

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'The miracle of hearing includes that human ears are uniquely tailored to pick up and enhance the sound of a human voice.'

~Bagatto et al. (2023)

Introduction

Children are born with the need and the ability to communicate (either through spoken language or through visual language). This chapter focuses on hearing aid fitting (HAF) to promote optimal auditory access for spoken language development. Measuring the ear canal's response to sound (in sound pressure level [SPL]), referred to as the Real Ear Unaided Response (REUR), has made it clear to researchers that the human ear, through the outer ear canal and the concha, naturally amplifies sounds within the 3 kHz to 4.5 kHz range, which encompasses critical frequencies for speech perception (Bagatto and Scollie 2023).

A hearing healthcare professional (HHP) should always aim to identify hearing loss (HL) as early as possible and, if the parents choose this option, to fit hearing aids (HAs) very soon thereafter. As a mother once said, after an early inconclusive hearing test, two weeks of waiting for the follow-up test might not seem like much to the HHP, but for her baby it is precious time lost. Every passing day matters. It is critical not to delay diagnosing and fitting HAs. Appropriate technology as part of early intervention can change the course of a child's entire life.

Paediatric Hearing Aid Candidacy

The main aim of amplification for children should be to provide audibility of the speech signal, to ensure that the child has access to speech and to allow the child to participate in conversations. With these aims in mind, amplification should be considered for any degree of HL, from slight to severe. There are many factors that will guide and inform HAF, and the management of the process should always be a team effort. The child's parents and family, the paediatrician, ear-, nose- and throat (ENT) specialist, speech therapist, teacher and others form part of this team and should be integrally involved in the selecting and fitting of the HAs (Chapter 14). Managing HL and HAF should be an ongoing process that should be closely monitored to accommodate all variabilities along the way:

- Are there any hidden co-morbidities that were initially missed?
- Is language and speech developing as it should?
- Is the child's environment changing and should the HA or amplification be adapted to accommodate these changes?

All of these questions and more should be asked at the beginning of and throughout the process of selecting HAs. The answers will guide the selection and inform the fitting of HAs. The underlying cause of the HL should be identified where possible; this could give an indication of whether the HL is progressive or not. Even if the aetiology is uncertain, ongoing monitoring to assess progressive HL is essential (Chapter 2). An infant or child with a severe to profound HL might not wear HAs long term as they may be candidates for cochlear implants (CI). Whereas some children with obvious middle ear pathologies (atresia, for example) might enter a bone conduction hearing device (BCHD) programme at once (Chapter 11), most of the paediatric population with HL will be long-term HA wearers.

There are a few important characteristics of the paediatric population that will guide every part of the HA process, from candidacy to verification and fitting of the HAs. These include:

- The etiology of the HL
- The size of the child's ear canal (external meatus)
- The nature of HA sound processing
- The changing communication needs of the developing child
- The sound environment of the infant and child
- The unique and evolving needs of the moving, learning child

Candidacy criteria

Infants and children with HL greater than 30 dB HL across the frequencies of 0.5, 2 or 4 kHz in any ear are considered candidates for amplification (Bagatto and Scollie 2023). Considerations for unilateral and bilateral hearing loss (BHL), as well as for different types and configurations of HL, will be discussed.

a) Unilateral hearing loss (UHL)

Without access to sounds from both ears, children miss binaural cues important for localisation and hearing in background noise. Binaural hearing is important in communication and provides advantages especially in coping with background noise. A child with a UHL is at greater risk for academic failure and difficulty in social situations (McKay, Gravel and Tharpe 2008). Recently, studies have also focused on listening-related fatigue as a contributor to difficulties experienced by children with UHL. School-aged children with UHL are at risk of the same level of fatigue experienced by children with bilateral moderate degrees of HL (Bess et al. 2020). In the case of infants with UHL the same principles of early intervention as with BHL apply. The etiology of the HL will give important clues about the nature of the HL and whether it might be progressive or associated with other co-morbidities. Children with mild-to-severe UHL are candidates for a HA on the affected side. Ongoing monitoring of UHL is critical.

Mild UHL in children, though often overlooked, can significantly impact auditory development and classroom functioning. Bess et al. (1998) found that children with minimal or unilateral sensorineural hearing loss (SNHL) frequently demonstrate reduced speech perception in noise, poorer academic performance and increased listening effort, indicating that such losses are not benign. Bagatto et al. (2019) and Scollie (2005) emphasise that even mild losses can compromise access to soft speech sounds, particularly in complex listening environments. Clinical management should include amplification when appropriate, remote microphone (RM) systems and functional assessments to monitor the child's auditory access and communication development over time.

If the UHL is moderate to severe, a HA is the first choice for amplification and all the same principles as with bilateral HAFs will apply in terms of the selection and fitting process. In the case of a profound UHL or Limited Usable Hearing Unilaterally (LUHU), an HA might not be an option. A contralateral routing of signal (CROS) system might be recommended, where a

microphone is encased in a behind-the-ear (BTE) style HA casing on the side with HL and a receiver on the other side. Sounds are then transmitted wirelessly to the normal hearing ear. CROS systems are recommended, and widely used, as a treatment option for LUHU in adults. There is conflicting evidence of benefit using this option for children. In a quiet environment, speech will be transferred from the side with HL to the normal hearing ear. In the presence of environmental noise, however, interfering noise will also be transmitted to the hearing ear. A CROS system is also unlikely to aid in localisation of sound. This system will require the ability to manage the device and the listening environment and is therefore not recommended for infants and young children. As soon as the child reaches an age where they can trial the CROS system and are able to manage the device, a CROS trial can be considered. This is typically around five to seven years of age, depending on developmental, cognitive and language abilities. The occlusion of the small normal hearing ear of the infant or young child is another risk when fitting a CROS system. An important benefit of binaural hearing is the ability to hear in background noise and a child with LUHU will therefore need additional support in noisy environments such as classrooms. An RM system is the best option for this situation (Oosthuizen et al. 2021).

b) Bilateral hearing loss (BHL)

In the case of mild BHL, the effect of ear canal acoustics on the hearing thresholds of the child should be considered when using the audiogram as the standard for candidacy for mild HL in the paediatric population. Ear canal pressure (ear canal SPL) is higher in a smaller ear than it would be in a bigger ear. This is important to keep in mind since the dial reading of the audiometer (using dB HL) is calibrated using the 2-cc coupler that typically has a lower ear canal SPL than those of infants and young children (using inserts of ear moulds). This difference is called the real-ear-to-dial difference. When the ear canal acoustics are taken into consideration, children may have poorer hearing thresholds than shown on the dB HL audiogram. Another potential negative consequence of this is that the child's ear canal grows over time and the sound pressure in the ear canal decreases. As a result, the hearing thresholds (in dB HL) will seem worse even if the child's auditory function does not change. It might be perceived as a progressive HL, when in fact it is just the result of a growing ear canal. Considering the effect of ear canal acoustics on the audiometric thresholds of infants and young children is important when making decisions about HA candidacy (using the Real Ear to Coupler Difference [RECD] measurement). RECD is also applied during the fitting process to consider the effect of the individual ear canal acoustics with amplification. RECDs will

be covered in the next section of the chapter. Using RECDs to convert dB HL to dB SPL and then using the speech intelligibility index (SII) (American National Standards Institute, 1997) is the recommended approach when applying candidacy criteria for mild HLs. The SII is used to quantify speech audibility either with an HA (aided SII) or without (unaided SII). The SII accounts for the child's ear canal SPL and estimates the audibility of speech sounds and the impact of HL on communication.

Another consideration when deciding to fit a child with mild BHL with HAs is the ability to provide a vent in the ear mould. An occluded ear canal will not allow sound to escape in the low frequency region and might provide sound where there is no need for HA gain. The upward spread of masking, a phenomenon where a lower frequency sound spills over and masks the higher frequency sound (Bess and Tharpe 1986) should be considered. When using an HA, this happens when low-frequency amplification spills over and masks high-frequency speech sounds. Instead of benefiting the child with HL, it will degrade the speech signal, especially in noisy environments. One way of ensuring that the low frequencies do not interfere in this way is through venting the ear mould sufficiently, which is something that might not be possible with the very small ear canal of an infant or small child. Figure 10.1 from Bagatto and Tharpe (2014) can be used to guide the decision on whether to fit the child with a mild bilateral or unilateral HL with HAs.

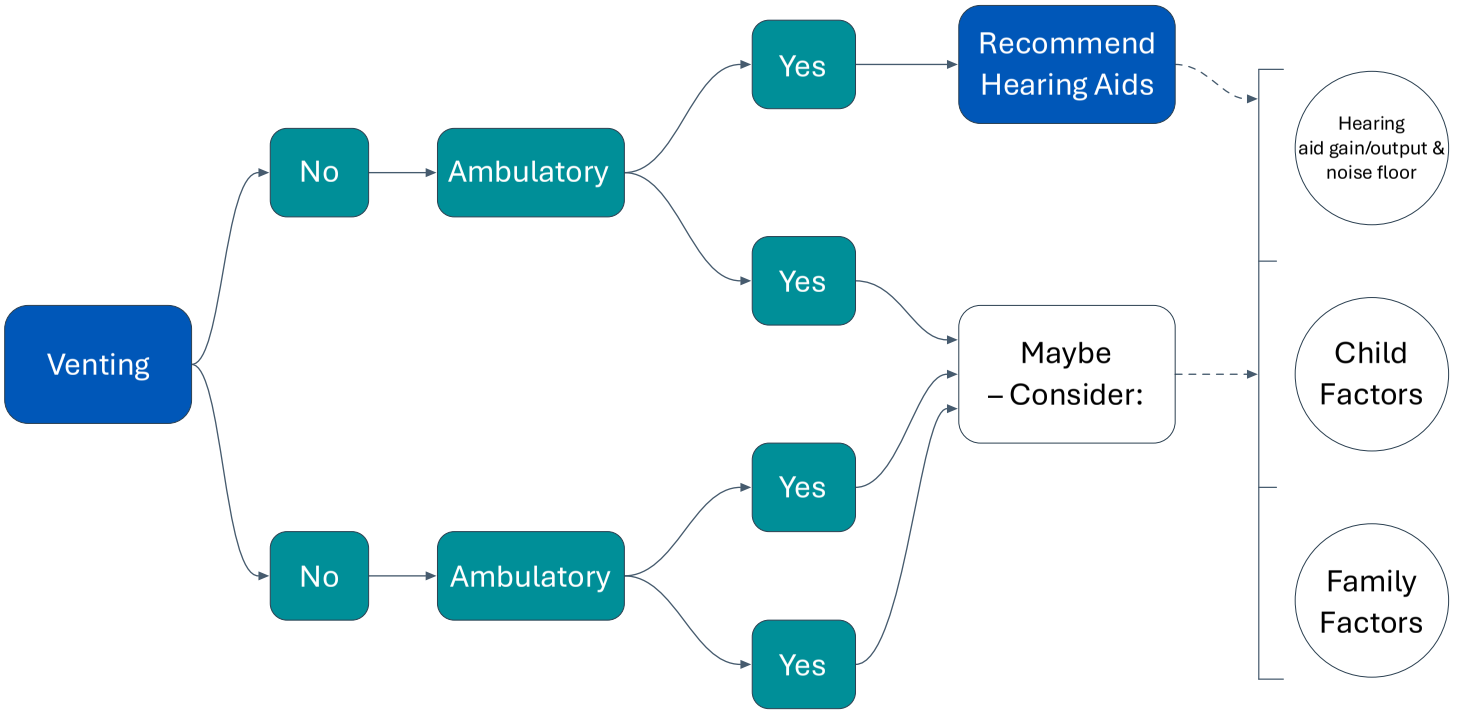


Figure 10.1: Decision support guide for HHPs considering HAs for children with mild BHL. Source: Bagatto and Tharpe (2014)

The term ‘ambulatory’ in this figure refers to the mobility of the child, whether the child is crawling, walking, stationary on the mother’s lap or in her arms. Speech intelligibility is negatively affected when the child moves away from the speaker and the signal-to-noise ratio (SNR) diminishes as the distance from the speaker increases. That should also be taken into consideration when deciding to fit a child with mild bilateral HL with HAs.

In the case of moderate-to-severe BHL, there is no doubt that a child with this degree of HL should be fitted with HAs as soon as possible. Children with severe-to-profound HL will potentially be candidates for HAs even though the HL might be better suited for a CI. In the case of babies and small children, several factors should be considered when fitting a severe-to-profound HL with HA. HA feedback, due to high gain levels and increased ear canal SPL, might be a problem. Depending on the severity of the HL, the aided SII might be too low and therefore not provide enough speech sound audibility, which is critical for language development. It is recommended that these children be fitted with HAs as part of the CI evaluation in conjunction with the CI team (Chapter 11). Candidacy for HAs for children with mild and profound HL will be considered in more detail in the following section.

Types and configuration of hearing loss

In the case of certain types of conductive hearing loss (CHL), such as atresia, an air conduction HA is not an option; rather, the child will be a candidate for implantable bone conduction devices. On the other hand, some types of CHL in children (such as otitis media) can be treated and the ENT surgeon plays a crucial role in diagnosing and treating these pathologies (Chapter 9). However, there are also types of CHL that, despite their apparent ‘treatable nature’, persist and leave the child with a semi-permanent HL. Any child with an HL that could negatively impact their ability to learn language and develop speech or to perform well in the classroom should be considered a candidate for HAs. A recent study (Pienaar 2021) showed that HAs are beneficial for children with CHL. Another example of a CHL for which HAs can be fitted while awaiting surgery is with a tympanic membrane (TM) perforation. It is not uncommon for a child to be left with a perforation in the TM after insertion of grommets (Vlastarakos et al. 2007). Surgery is not always an immediate option after a TM perforation, and it is therefore often associated with HL. HAF is a viable option for providing the necessary amplification in the interim. Infants and young children with SNHL are candidates for air conduction HAs. These infants and young children will show clinical evidence of impaired outer hair cells (such as absent otoacoustic emissions [OAEs]).

Auditory neuropathy spectrum disorder (ANSD) is more complex to manage than typical SNHL and the prognosis for spoken language development is uncertain. Conventional guidelines for SNHL management do not apply to ANSD. As behavioural testing in young children is often unreliable, management of ANSD in the paediatric population is likewise difficult. Controversy still surrounds the recommended management of young children with ANSD, since the benefits of HAs in aiding the development of speech and language are unclear for this population. On the one hand, the HA may be providing amplification to a system that does not require it, and on the other hand the HA may be amplifying sounds that remain unclear and therefore meaningless to the child.

Spectral and temporal processing deficits are associated with ANSD and amplification through HAs cannot overcome these deficits. CI constitutes the major rehabilitative intervention that allows for speech perception in patients with bilateral ANSD who do not benefit from conventional amplification. The clinical HHP is faced with these questions: 1) Should HAs be offered to infants with ANSD? and 2) How long should HAs be trialed before deciding that the outcomes are not appropriate? While HA trials are warranted, children with ANSD must be tracked closely to avoid delays in decision making.

Key Considerations in Hearing Aid Selection

When deciding on the HAs features for children, it is essential to consider four key factors that influence the decision-making process.

- First, the nature and severity of the child's HL must be carefully evaluated.
- Second, their sound environment plays a significant role, including exposure to noise, whispering, sports and music.
- Third, the unique aspects of their developing brains and bodies should be considered, as growing auditory systems require a clearer signal and factors such as ear size, acoustics and other health conditions can impact HA selection.
- Lastly, the family context, including support systems and communication needs is critical in determining the most appropriate solution.

These factors will guide the HHP's decisions about HA features essential for infants and children. Each factor should be considered when making decisions about specific HA selection, to ensure that every aspect of the child's unique hearing needs is considered.

The nature of childhood hearing loss

HL in children differs from adults in meaningful ways. HL in children is more severe, more asymmetrical and more progressive than that of adults (Pittman and Stelmachowicz 2003). Once HL has been confirmed, the HAs chosen should be flexible in terms of gain, output and configuration to accommodate any changes in hearing.

Children's sound environment

a) Noise and reverberant spaces

Once the infant with HL leaves the mother's arms and starts to move, noise will become one of the main challenges when choosing HAs. Children's schools and social engagement are characterised by noise and reverberant spaces. Noise management in HAs is used as an umbrella term for noise reduction, multiple programmes and directional strategies. The concern for HHPs is that noise management in HAs might take away from the speech signal or degrade the speech signal. Over the past decade noise management systems in HAs have evolved and there is good evidence that children benefit from new technology, adaptive gain and noise reduction systems (Pittman and Stewart 2023).

In a recent study investigating the data gathered from 19,201 paediatric HAFs (newborn babies up to children eighteen years of age) through the data logging systems in the HAs, it was found that wearing time of HAs increased with higher levels of technology (Pelosi 2024). Higher levels of technology employ more noise management systems, which makes HAs more comfortable to wear in noisy situations and as a result daily wearing time increases. Directionality is another way of improving SNR for managing background noise. Traditionally, the HHP had to choose the HA programme to receive sounds equally loud from all directions or louder from the front. Directional HA microphones, developed to minimise the negative effect of background noise, however, assumes that the child faces the speaker. Children have a low rate of orienting their face to the speaker (Scollie et al. 2010) and localisation only matures from age six onwards. Toddlers, once they start to crawl, move away from the speaker and overhearing across all directions is important in the early years. Traditionally, omnidirectional mode was the preferred choice for young children's HAF. Adaptive directionality in newer technology instruments is a beneficial strategy to leverage the benefits of both omni- and directional HA features (McCreery et al. 2012).

As soon as toddlers start to move away from their parents or enter noisy educational environments, they will be candidates for assistive listening devices (ALDs), in addition to their personal HAs. ALDs, such as RM systems, have been successful in improving listening environments with poor SNRs, overcoming the negative effect of reverberant rooms and compensating for substantial distances between the child and the teacher or caregiver. The RM system makes use of a remote microphone attached to the speaker, connecting wirelessly to the HA of the child. Even if the child is far away, the speaker's voice will be perceived to be close by, overcoming the background noise, distance and negative effect of the echoes in the reverberant room.

b) Sports

Other sound characteristics of children's environments include their participation in sports. Moisture management systems and HA durability should be diligently considered as well as the distance and reverberation that inevitably play a role in these circumstances. HA compatibility with ALDs and timeous introduction of these systems are important. As with noise, an RM system with a remote microphone attached to the sports coach, for instance could aid participation for the child with HAs. Children who participate in sports also sweat and are exposed to dust, which needs to be considered when choosing HAs.

c) Music

Music training for children with HL should be encouraged as a complementary means of habilitation to improve language and listening outcomes (Lo et al. 2020). HA signal processing for live music and music performance should support music lessons.

Children's brains and bodies

a) Developing speech and language

Since children's auditory systems are still developing, HAs should provide a clear signal with more bandwidth, a better SNR and a higher SII than HAs for adults. Children's speech and language abilities are developing, and access to all speech sounds should be the goal of amplification. Children might not have access to some high-frequency speech sounds, such as /s/ or /sh/ because of HL severity or feedback issues, due to small ear canal sizes. Certain

signal processing strategies aimed at lowering the inaudible frequencies to provide access to these high frequency sounds should be considered. This technology is evolving, has been shown to be efficient and should be implemented when fitting HAs to infants and children (McCreery et al. 2012).

b) Ear canal size

Ear size affects acoustics. When prescribing HA gain and other electro-acoustic measurements for the infant and child's hearing, an individualised prescription should be used, which considers the age and HL of the child. Many infants are born with sufficiently developed pinnae and ear canals to support an HA connected to a custom ear mould. BTE HAs are the appropriate choice for most infants and young children. The pinnae will only be fully grown by the age of ten, and the concha will show rapid growth in the first two years of life. Regular ear mould changes are essential to ensure well fitted HAs. Venting the ear mould will not be possible with a very small ear canal. Soft material (silicon or vinyl) are safe options compared to hard material, such as acrylic. Due to the rapid growth changes and resultant ear mould changes, certain HA types such as in-the-ear or canal (ITE/ ITC) are not practical options for infants and young children. Custom products are also more prone to feedback due to the proximity of the receiver and microphone. Receiver-in-the-canal (RIC) HAs look like other BTE HAs but have the receiver in the ear canal instead of being housed in the HA casing. These HAs are less secure than BTE HAs as the receiver can easily be blocked with wax, needing a daily wax check. For this reason, they are not suitable for discharging ears. The RIC type aids can be considered as an option for older children and teenagers.

Children's family contexts

Supporting the caregiver means supporting the child. Apart from the emotional toll of the HL and possible other disabilities of the child, caregivers will also experience practical barriers. Besides the cost of the devices often being very high further ongoing expenses might be required, such as insurance (in case of breakage or loss), challenges with HA retention, regular ear mould remakes and appointment scheduling. The HHP might need to assist the parents in securing funding, or choose HAs that are less costly, without compromising essential features (Chapter 15). If the child has any other disabilities, inter-professional collaboration will be needed. In that case,the HHP will need to support the caregiver to ensure collaboration. At various points in the journey, caregivers will need additional support in connecting them

to the necessary professionals and other parents of hearing-impaired children and in transitioning the child from childcare to school. The use of ALDs such as RM systems will require training and support to the caregiver and teacher. Some practicalities might seem trivial to the HHP but might be a barrier for the caregiver. For instance, rechargeable HAs might be a safer option for the young child (since loose batteries could be swallowed), but if the family does not have constant and good sources of electricity, the HAs will not be optimally charged. Rechargeable HAs might also be more expensive. Finally, caregivers' expectations should be realistic and should be supported to ensure that the quality of the language input is sufficient for optimal outcomes for the child. Regular contact with the caregiver is of utmost importance. This contact might be through cellphone apps, messaging, calls or visits. The HAF is just the start of the process and not the end goal.

Assistive Listening Devices (ALD)

The most widely used of the ALDs are RM systems. These systems use radio frequency signals to transmit sound directly from a source (like a teacher's microphone) to the child's receiver. The speaker's voice is carried to the child's HAs or CI. Because of the proximity of the speaker's mouth to the microphone, the distance between the teacher and child or the child and parent is minimised. RM systems effectively lower the signal to noise ratio, overcoming distance and reverberation. They are often used in classrooms to help children with HL hear their teachers.

Newer technology HAs offer Bluetooth connectivity and Bluetooth streamers can be used as an alternative to RM systems. Bluetooth capability has also opened the doors for other systems that might be helpful. Smartphone connectivity facilitates the use of applications for listening activities or even text messaging and other communication aids. Activities should be age appropriate, and their usefulness should be investigated by the HHP, the child's family and other team members.

Other types of ALDs include:

- Infrared systems used with the television
- Sound Field Systems that use strategically placed speakers in a classroom to enhance the speech signal for all students, including those with auditory processing challenges or mild to moderate HL

- Loop systems that utilise an electrical current in a wire loop to transmit sound directly to HAs or cochlear implants that have a 'telecoil' feature
- Flashing and vibrating alarms
- Telephones that make sounds louder

Fitting of hearing aids

Electro-acoustic requirements: Fitting to target

The single most important refrain in the HHP's mind when fitting HAs to infants and young children should be:

In the context of early intervention, infants will wear their HAs at fixed, clinician-determined settings for months or years before they are able to clearly express their preferences. Therefore, the validity of the clinician-determined HA settings may be of crucial importance for auditory development in the early years of life. (Scollie 2005).

A child is not just a small adult. When HHPs fit HAs on children, they must use all the tools available to them to ensure that the child will be able to hear speech. A child needs to receive sound consistently and at safe and comfortable levels to hear speech and learn language. Consensus in the field is that HA prescription should be done in an objective way (Bagatto et al. 2023; Pittman and Stewart 2023). A prescriptive fitting formula provides systematic and consistent fitting that ensures that speech is audible and comfortable for children at different input levels. This is done by calculating the amount of amplification that is needed to ensure audibility of the incoming signal. A specific amount of gain is then prescribed per frequency, and this is individualised for each child. Other electro-acoustic parameters, such as output, maximum power output (MPO) and compression ratios, are also prescribed. HA performance is then measured against this target.

There are two methods specifically suited and most widely used as the algorithms of choice when fitting children. These are the Desired Sensation Level (DSL) v5.0a (Scollie. 2005) and the National Acoustic Laboratories (NAL) Non-Linear 2 (Byrne et al. 2001). Numerous studies have shown that school-age children with HAFs that approximate the targets of these two prescriptions achieved high levels of aided speech understanding, audibility and loudness comfort over a wide range of input levels (Pittman and Stewart 2023). These formulas are

preferred above the HA manufacturers' algorithms because they are grounded in empirical evidence specific to the paediatric population. These prescriptions consider the child's hearing thresholds, age, language (tonal or non-tonal) and ear canal size and adjust the target values based on these variables.

DSL v 5.0a or the NAL-NL 2 formula

There are several differences between the two strategies. The most significant difference is that the DSL prescribes more gain than NAL for soft speech for children with the same HL. NAL provides more comfort in noise through higher compression thresholds than DSL. Different studies have shown that children (when they are old enough to express a preference), prefer the DSL for quiet speech and the NAL for noisy situations. Despite these differences, children's early speech and language outcomes and the ability to perceive conversational speech are similar for the two prescriptions (Ching et al. 2013; Scollie et al. 2010). Research indicates that while children can discern differences between the DSL and NAL prescriptions, these variations have minimal effect on overall communication outcomes. That leaves the HHP with the choice to use either of these prescriptions for optimal outcomes.

As hearing instrument technology advances, HHPs should base their decision on a combination of all factors. For instance, if it is available and the child's HAs have adaptive situational gain (ASG) (currently available in higher technology levels that are typically also more expensive), more audibility for soft level inputs can be obtained through ASG. In this case, the HHP might opt to use the NAL formula since the additional input that the DSL might add at soft levels will be achieved through the HA processing (Pittman and Stewart 2023). If the infant has a moderate-to-severe HL and maximum audibility of speech is the aim, then DSL is the formula of choice. The SII values, a numerical estimate of audibility across the frequency range of speech can be used to quantify the audibility of speech. Frequencies are weighted based on their contribution to the average speech; the Long-Term Average Speech Spectrum (LTASS) and percentage value is calculated with 100% representing complete audibility (ANSI 1997). If fitting to the NAL target results in a low SII value, the DSL target should be used to ensure audibility of speech.

Whichever of these two prescriptions the HHP chooses, the fitting should be verified at different input levels and frequent follow-up visits and feedback from the caregivers should be gathered to make sure that speech and language development is optimal.

Rationale for objective verification of the HAF

Prescriptions are defined electro-acoustically (gain, output, compression ratios) and should be verified using specific electro-acoustic measures to ensure that the prescription is achieved (Scollie 2005). Aided sound field measures have previously been used to verify HA settings, but their usefulness is limited to counseling and proving benefit. The electro-acoustic parameters that need to be verified are optimum gain at different inputs and across the frequency spectrum, and the maximum power output of the HA to ensure that it is not too low (which causes distortion) or too high (which causes discomfort). If it is found that audibility in the high frequencies is too low, frequency lowering is recommended, which should be verified using a 's' and 'sh' signal.

During the HAF process, modern HAs are connected to the manufacturer's software directly or wirelessly. The software recommends electro-acoustic settings based on the child's age and HL. These pre-fitting recommendations provide a good starting point for the fitting. It is not uncommon, however, to find discrepancies between the actual performance of the HAs and the prescriptive targets for gain and output during verification measures. Without verifying the HA performance in the child's own ear, the HHP cannot assume that speech will be audible and loud sounds comfortable. It is crucial to account for the increase in real-ear SPL when fitting HAs to infants and young children (Stelmachowicz 2000). The best way to do this is to obtain real-ear measures of gain and output using a probe microphone system. Performing traditional probe-microphone techniques, where the child must sit still for the insertion of the probe in the ear canal, and remain quiet and still with the head in an upright forward-facing direction for a prolonged time, is not always possible with younger children. Therefore, simulated or coupler-based real-ear measures are the verification method of choice because infants and young children cannot sit quietly facing a loudspeaker for the duration of real-ear verification. Furthermore, a controlled test-box environment is an accurate and reliable way to measure the RECD.

The RECD procedure requires minimal co-operation from the child and can be performed in less than five minutes. All subsequent measures can be performed in a test box and the RECD can be applied to predict real-ear gain and output. New RECD measures should be obtained each time the ear mould is replaced. The HA must then be adjusted to best match the targets to ensure optimum audibility of the speech signal. HA performance across input levels in the range of 55-75 dB SPL should be conducted to determine the audibility

and compression characteristics of the HAs. This should be done using a calibrated pre-recorded speech signal. Equipment often incorporates equipment-specific speech passages as a signal for measurements (such as the 'carrot' passage in the Audioscan equipment). This kind of signal, however, incorporates only one language. An internationally used, standardised speech signal that is available in most probe microphone measurement equipment is the International Speech Test Signal (ISTS). It includes the relevant properties of speech and allows for reproducible measurement conditions (Jorgensen and Novak 2022). The languages that were incorporated in the development of this signal is American English, Arabic, Chinese, French, German and Spanish (Holube et al. 2010). The ISTS is shaped by LTASS targets, which are calculated using the prescriptive target (NAL or DSL). This is the signal of choice when verifying HA function for children.

If frequency lowering is employed in the HA, verification procedures should be included for this technology. Frequency lowering can potentially lead to spectral overlap and perceptual confusion of /s/ and /sh/. Using calibrated /s/ and /sh/ sounds, the audibility of the sound with amplification can be determined. If the upper limit of the curve is above the threshold at the particular frequency, the /s/ sound is audible, if not, frequency lowering is activated and adjusted to ensure that the sound is audible, but not overlapping the /sh/ sound. The maximum output of the hearing instrument must be verified to ensure that it does not exceed uncomfortable levels and is not set too low, causing distortion. This is done by using a high intensity signal of 90 dB SPL, such as a broadband stimulus.

Frequent visits to the HHP for HA adjustments are an important part of the infant's ongoing habilitation (every two to four months) to re-assess thresholds and adjust RECDs.

A Step-By-Step Guide to Fitting Hearing Aids

Once the candidacy for HAs has been established (through diagnostic tests and evaluations by the ENT specialist and other relevant team members) and the HAs have been selected, the HHP should immediately proceed with taking ear mould impressions.

Procedure for obtaining ear impressions

The prescription for the ear moulds should include the length of the canal and helix, material (silicon, etc.), tubing type and vent (if possible). The child's ear moulds should be made of

soft material for comfort, safety and retention. BTEs are the HAs of choice for infants and younger children. For older children, RIC HAs can be considered and acrylic tips might be an option, depending on the degree and configuration of the HL. Impressions will also be needed for these tips.

1. It is important to start with an explanation of the process of taking ear mould impressions for the parents. If it is an older child, illustrations might be helpful. Rapport should be built and the child put at ease. If it is an infant, the caregiver could be encouraged to feed the baby to maintain calm. If the child should get upset during the procedure, it might be helpful if the parent holds the child gently but firmly with one ear against their chest. It is important to discuss the expected duration of this support and suggest distraction techniques to keep the child calm until the process is complete. An otoscope, ear light, otoblock, distraction toys, impression material and the syringes should be ready and available.
2. It is also important to adhere to hygiene protocols, like washing hands thoroughly or using gloves. Wearing a mask is compulsory. It is furthermore necessary to keep talking to engage the child.
3. An otoscopic examination should be conducted. The ear canal should be examined to ensure there are no conditions, such as discharge or excessive cerumen, that would prevent taking an ear mould impression. The size and length of the ear canal should be assessed. To demonstrate the process to older children, it is often helpful if they inspect their parent's ear (while the HHP holds the otoscope) or an ear model, if one is available. The HHP could furthermore shine the light of the otoscope on the child's hand.
4. Before the ear light is used, it should be marked to ensure that it is inserted at a safe depth. The guidelines are ten mm from ear canal entrance for children younger than six months and ten-to-fifteen mm from entrance for children older than six months.
5. The otoblock should be inserted using the marked ear light. For this part of the procedure, the mother or caregiver should gently press the child's head against their chest with one hand against the child's cheek (Figure 10.2). For young children, the standard sized otoblock could be halved by pinching off a piece. The otoblock should be gently placed into the ear canal until the mark aligns with the canal entrance. The depth and position of the otoblock should be verified with an otoscope and a string wrapped over the ear to secure it. The same should be

repeated for the other ear if it is a bilateral fitting.

6. With both otoblocks secured, the impression material should be mixed in the amounts specified by the product directions. Once mixed through, the material should be loaded into the syringe, ensuring it is ready for application. For an older child the material could be mixed for them to see and a small amount of material could even be handed to the child to mix and roll, although caution should be taken that it is not swallowed.
7. The child's head should be softly secured and the loaded syringe positioned in the ear canal. It is important not to pull the ear or press against the ear as it will alter its shape and may cause an inaccurate impression. The canal should then be filled by slowly depressing the plunger. The syringe should not be pulled out, but should rather slowly be pushed out by the syringe: The canal should be filled first and then the concha. Inject the material into the angle of the helix using the syringe. The tragus should be gently pressed to confirm it is adequately filled. Gentle jaw movements during the process by sucking or drinking are encouraged. This stepwise procedure should be repeated on the other side if it is a bilateral fitting. It is important to ensure that one does not press against the impression material, changing its shape. It might be necessary to wait until the first impression has hardened before moving on to the other ear.
8. The material is set when pressing a fingernail into it leaves no indentation.
9. The pinna should be gently pulled to loosen the impression. The bottom part of the impression should be lifted by the HHP, using a finger to break the seal, and gently pulled from the canal, concha and then the helix. It is important to ensure that the otoblock has been removed along with the impression material. Otoscopy should be conducted after removal, to ensure that no impression material has been left in the ear canal.
10. If there are no holes or bubbles and the canal seems long enough, the impression can be sent to the manufacturer.
11. Ear moulds should be replaced regularly (Figure 10.3). For the infant this means every two months. As the child grows older, the caregiver should regularly assess the fitting. If feedback occurs or the ear moulds visibly do not fit, they will need replacing. It is important to communicate this with caregivers from the start.



Figure 10.2: Taking the ear impression while the infant is being fed

Procedure for pre-programming hearing aids

Most new technology HAs are connected wirelessly to the manufacturer's software. Choose a manufacturer that supports paediatric fittings through dedicated research and whose HA software includes the DSL or NAL prescriptive target. These HAs will also have default settings based on the age of the child, incorporating changes in the ear canal, and will suggest frequency lowering if possible. If you are unsure, contact the company representative and learn as much as possible about the paediatric settings of the HAs you choose.

The process of pre-programming includes:

1. Once the HAs are received, and before the fitting appointment, the adult size tone hook should be replaced with the paediatric size tone hook. These smaller tone hooks come in a variety of colours. The caregivers should be encouraged to let the child choose the HA and tone hook colours to increase adoption rate and retention.



Figure 10.3: BTE HA with silicon ear mould.

2. All fields should be completed with appropriate software, for example, age, audiogram, etc. (with as much information as possible).
3. DSL or NAL software algorithms should be chosen. Generally, the DSL prescription would be the prescription of choice for infants and young children with moderate to severe HL or for progressive HL. NAL could be considered for milder HL, older children in noisy school surroundings or if the HHP gets feedback that it might be too noisy, and retention becomes a challenge. Outcome measures and feedback from the caregivers are crucial to guiding the decision.
4. The manufacturer's default setting should be used as a starting point for the fitting (including activation of noise reduction systems and frequency lowering).
5. The HHP should make sure that the volume control on the HA is deactivated. Access to these features is possible nowadays through HA applications for most smartphones. That way the caregiver has control over the volume settings, if needed.
6. The settings should be saved and the HAs should now be ready for verification at the fitting appointment.

Procedure for fitting the hearing aid in the child's ear and performing the feedback test

On the day of the fitting, a two-hour session should be scheduled with the caregivers and child. If the HHP does not schedule enough time, anxiety might be created for both the HHP and the caregivers should something unexpected happen (a crying infant, programming glitches, tears, etc.). A story picture or written information sent ahead might be helpful to prepare caregivers for all the steps in the process.

1. The ear mould should be placed in the child's ear to ensure that it fits well, and to cut the tube to the correct length. Even though the first fit is part of the preparation for the fitting and not for the purposes of instructions to the parents yet, the HHP can talk through the insertion of the mould. Repetition is key. Insertion in the ear canal should be demonstrated. The HA should fit snugly behind the ear. After the correct length of the tube is marked, the HA can be attached to the ear mould.
2. The HAs should be connected to the software and the instruments muted.
3. The HHP should ensure that the child is comfortable and occupied (or feeding) and should then insert the HAs in both ears. Due to the small ear canal size and increased ear canal SPL, HA feedback often occurs with paediatric HAFs. The child should be kept as quiet as possible and the feedback test for both ears should be run through the manufacturer's software. Often these loud sounds cause the infant or young child to cry, so it may be helpful to keep a distractor close by. The feedback test requires a quiet baby. If the baby is asleep, they can be kept in a sleeping state for as long as possible.
4. The HAs should then be removed and prepared for the RECD measurement.

Procedure for verification of the hearing aid fitting

Verifying the match to prescribed electro-acoustic performance is the next essential step in a scientific approach to paediatric HAF. This should be done using RECD measurements and the HA test box coupled to the HA-2 coupler (Figure 10.4). RECD and the coupler is the verification method of choice for infants and young children. Once the child can sit upright facing the speaker for as long as it takes to verify the fitting and programme the HAs, REMs are possible. This is usually after the age of six. If it is not possible to measure RECDs (the child cries too much or moves, for instance) age-related predicted RECD values can be used. These can be incorporated into the probe microphone system and can be chosen as an option. If RECDs have been measured previously (recently), it can be entered as values and the HHP will not need to measure it again. RECD values from the one ear can be used for the other side as well, if there are no obvious significant differences in the anatomy of the ears. RECDs should be remeasured regularly as the child's ears grow continually. RECDs should also be remeasured every time the ear moulds are replaced. Instructions on how to perform the RECD is equipment specific.

Procedure for measuring the RECD

1. The coupler microphone of the equipment should be connected to the transducer to measure the coupler. The coupler should be connected to the coupler microphone of the equipment and the transducer should be coupled to the other end of the coupler.
2. In equipment software, the HHP should select the option to measure the coupler. A broadband or sweep frequency, generated by the system, is delivered to the coupler and its response is measured by the microphone.

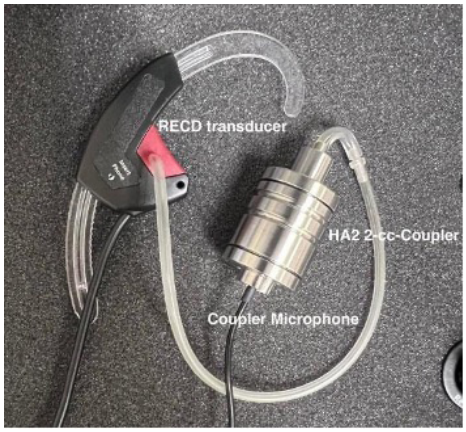


Figure 10.4: RECD equipment

3. Following this measurement, the real ear SPL of the child should be measured. The coupler and ear coupling parameters should be entered correctly into the verification system so that accurate conversions can be applied. The same stimulus should be presented and the real ear response measured and used to obtain the RECD values.
4. For the RECD measurement, a probe tube is inserted in the ear canal (Figure 10.5) together with either the ear mould or the insert foam tip, coupled to the transducer. The probe tube and ear mould or tip should be inserted into the child's ear canal. Distraction techniques can be used to draw the child's attention away from the procedure. The probe should be placed so that it extends two-to-four mm past the tip of the ear mould or foam tip. After six months corrected age, the

probe tube should extend five mm past the probe tube. If the tube is not inserted deep enough into the ear canal, it can lead to inaccurate results, especially at the high frequencies. Ear mould lubricant can be used for easier insertion. The probe tube can be secured to the tip with plastic wrap or it can be placed separately from the tip and ear mould.

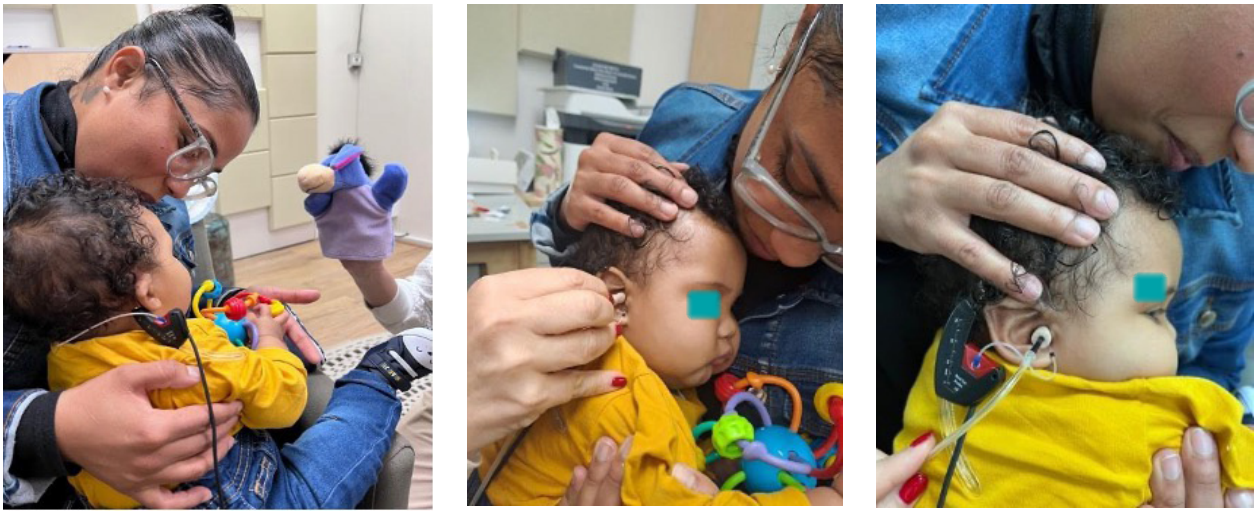


Figure 10.5: Inserting the probe tube and RECD transducer (with a foam tip) in the infant's ear

5. Next, the real ear should be measured. The same sweep tone that was used for the coupler measurement will be transmitted through the transducer. As a child's ear is smaller, the resulting ear canal SPL is higher. Therefore, ear canal measurements typically show positive RECD values in children (there are instances, however, such as with a perforation in the TM where the child's ear canal SPL will not be higher than the coupler values). Figure 10.6 demonstrates this difference in ear canal SPL.

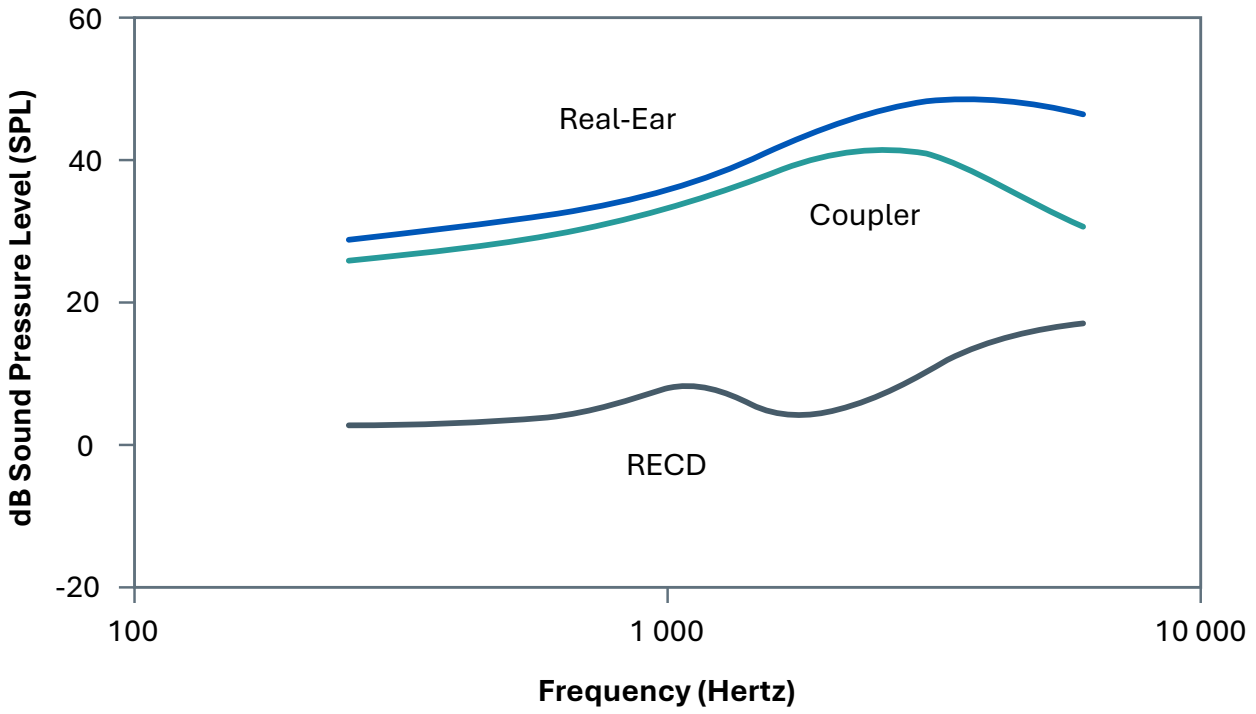


Figure 10.6: Higher ear canal SPL for a typical child's ear, compared to coupler values

If the values are not positive, it is important to make sure the probe tube is inserted deep enough. If the probe tube is blocked or pinched against the canal the real ear values will be very low. If an ear mould is being used it should be changed to a foam tip. If there is a drop off in the high frequencies it is possible that the probe tube is not inserted deep enough, or that there is leakage. The HHP should attempt insertion again or should replace the tip with a larger tip or else with the ear mould. If the child has a perforation in the TM or myringotomy tubes or if the ear mould vents are larger than one mm, the ear canal volume will be larger, with lower ear canal SPL and negative RECD values will be expected. This will result in more prescribed gain, which is appropriate for the child at this time. As the ear canal grows, RECD values will change. RECD values should be repeated regularly. As a guideline, the RECD should be remeasured when the ear mould is remade. RECDs from one ear can be used for the other side.

6. If, after inspection of the real ear curve, the HHP is satisfied that the real ear SPL values are valid, the probe tube and ear mould should be removed. The HHP can now continue programming and verifying the fitting in the test box, using the RECD values.

Procedure for verification of the hearing aid fitting by performing real ear measures (in the test box, figure 10.7)

1. Once the RECD has been measured, the HA should be placed in the test box coupled to the 2cc coupler. The test box should not be closed yet. One HA should be coupled (most systems can only test oe HA at a time), and one HA should be outside the box.
2. Both HAs should be connected to the manufacturer's software. The procedure should be repeated for the other ear after the fitting of the side is verified. The HAs should have already been pre-programmed to the manufacturer's default settings as a starting point.
3. If it was possible to measure RECDs, these values should be entered into the measurement equipment (some equipment is computer software-based, while other types of equipment will need the values to be entered manually). Age-appropriate predicted values can be used if RECDs could not be measured. If it is a follow-up visit, or RECD values have been measured before (this could have been done with the baby asleep after ABR testing, or during any other visit prior to the fitting) these values should be entered into the measurement equipment system or software.
4. The prescriptive target used to pre-programme the HAs should be chosen in the software (DSL or NAL) to generate targets in the system.
5. In the simulated (test box) real-ear section of the system, the HHP should choose a calibrated speech stimulus (ISTS if that is available). Noise reduction and frequency lowering should be disabled in the software for the verification process.
6. A level of 65 dB SPL should be entered to measure a simulated real-ear aided response. The HA should be adjusted to provide a close match to the average speech targets (LTASS) for 65 dB SPL. In general, these measured values should be within ±5 dBs of the prescription target. In the case of a steeply sloping loss or a severe loss, fit-to-target might not be possible. The HHP should use the upper limit of speech (the target line above the LTASS line in the middle) to gauge if these sounds (especially /s/) are audible. If not, frequency lowering should be activated.

7. Next, the HHP should choose a high-level (85 – 90 dB SPL) narrowband stimulus or EUHA MPO stimulus and adjust the HA so it approximates the prescriptive targets and does not exceed the predicted uncomfortable levels.
8. Step six should be repeated for soft (55 dB SPL) and loud inputs (75 dB SPL) to evaluate compression characteristics of the HA. The fit for average speech and MPO targets should not be compromised to obtain a better match for soft or loud speech. A close match to average conversational speech and maximum output targets of the HAs should be given priority when verifying HAs for infants and young children (Bagatto et al. 2023).
9. Once the HHP has adjusted the HAs at 55- and 75 dB SPL, the process for 65 dB SPL and MPO should be repeated.
10. The SII (ANSI S3.5-1997) values are available on most real ear measurement systems. During this verification process of HAs, the aided SII values should be displayed together with the DSL targets and HA verification curves. These values give a valuable indication of the audibility of speech.
11. If the HHP has determined that the child is a candidate for frequency lowering, it should be activated at this stage. The HHP should select the signal simulating /s/ and fine tune the frequency lowering setting until the upper shoulder of /s/ falls within the audible area (that is, above the threshold SPL at that frequency). It is recommended that the chosen setting employs the weakest possible frequency lowering setting, measuring the upper shoulder of the /s/ sound above the upper limit of speech. Associated SII values do not need to be recalculated based on the fitting with frequency lowering activated.
12. In the case of binaural aid fittings, all the steps should be repeated for the HA on the other side. The HHP should make sure to separate (unlink) left and right HAs in the programming software so that the programming that was done for the first HA is not lost.

Procedure for the verification of remote microphone systems

If a toddler or child has been fitted with an ALD such as an RM system, it should be verified. There are two objectives: To ensure that the active microphone does not change the HA gain or output when it is on, and to ensure that the microphone transmits sound to the HA.

1. After the HA verification is completed and fitted to DSL/NAL targets, the HA should be attached to the 2 cc Coupler and the response measured to the LTASS at 65 dB SPL, using the ISTS or calibrated speech.



Figure 10.7: Hearing aid set-up in the test box

2. If the HA has an RM receiver attachment, it should be attached now. Most new technology HAs have an integrated receiver. The RM transmitter should be activated (Figure 10.8a), and the 65 dB SPL measurement repeated with the microphone on, but muted. The curve should not change from the curve without the RM system attached, indicating that the amount of amplification is not affected (less) when the RM system is in use. If the SPL measurement is different, the RM gain should be adjusted in the HA software.

Figure 10.8: (a)



Figure 10.8: (b)



Figure 10.8: (a) RM transmitter outside the HIT, switched on, (b) RM transmitter inside the HIT, switched on

3. Next, the HA and the coupler should be removed from the test box (Figure 10.8B). The RM microphone should be placed in the test box and the signal presented. The microphone will now transmit the signal to the receiver in the RM system active in or attached to the HA. Again, the output curve should be the same as without the RM attached, indicating that the microphone is transmitting speech as it should.

Follow-up sessions and outcome measures

First visit

After the fitting and verification of the HAs, caregivers should be shown how to insert, clean, conduct a listening check, replace batteries or charge the HAs, and should be given advice on retention. It often works best to distract the child after initially inserting the HAs first thing

in the morning. Keeping the HAs in for the first two weeks will be the most important task for the caregivers. It is important to ensure all safety aspects are discussed, such as the danger of ingesting small batteries. All the other small parts should be put out of reach of the child and other curious siblings. Make sure the caregivers are comfortable with the HAs before they leave the session. If the child reacts to sound or benefit can be demonstrated, the caregivers will be more motivated to keep the HAs on. The HHP should give the parents a call the next day to ensure that the first day of wearing the HAs went well. The first follow-up should be scheduled for no longer than two weeks after the initial fitting.



Figure 10.9: A child with hearing aids being placed in his ears.

The following recommendations are made for follow-up visits and outcome measures:

Scheduling of visits

- First two years after the initial fitting: Every three months
- Thereafter: Every four to six months until the child reaches school age
- School-age children: annually or as needed

The following procedures or components should be part of every visit:

- Caregivers should be interviewed to address concerns or troubleshoot problems.

- Otoscopy should be performed.
- Tympanometry should be repeated.
- HAs should be tested in the test box/Listening check should be done by the HHP.
- Ear mould fit should be checked and replacement of the ear mould done if necessary.
- Unaided hearing evaluations (including speech perception testing) should be done regularly.
- Data logging should be reviewed to ensure regular use of HAs.
- RECDs should be re-measured as necessary and always if the ear moulds have been replaced.
- HAs should be re-programmed and re-verified with revised thresholds and RECDs.
- Aided hearing evaluation (including speech perception testing) should be done.
- Caregivers should complete validation questionnaires to ensure optimal audibility.
- Detailed notes should be made in the child's file regarding setting changes.
- Referral to other professionals should be made as necessary.
- Reports should be written after each visit and sent to the child's school and/or the professionals involved with the child.

Objective Validation Measures

HAF objective validation measures include aided sound field testing, as well as parent/teacher questionnaires. Once the aided SII is completed with the values obtained during real ear measures (if it was not done automatically by the measurement system [with the 65 dB SPL and 55 dB SPL input signals]), the HHP must determine if the HAF is electro-acoustically acceptable for the child's pure tone average.

Aided sound field testing: (when age appropriate)

- The child should be positioned so that loudspeakers are at head height and +/- one meter from the child.
- Narrowband noise or pulsed tones should be used.
- Ear specific results should be obtained at least at 2 kHz and 0.5 kHz (take into consideration that the degree of HL, auditory awareness, duration of HL and quality of HAs will affect aided thresholds).

- Aided speech perception: The same hierarchy as with unaided speech perception testing should be used. Speech should not be presented louder than 60 dB HL as loudspeakers will tend to distort sound. Ear specific speech perception scores should be obtained with and without lipreading.

Outcomes questionnaires

Developmentally-appropriate outcomes questionnaires should be used to provide complementary information on auditory development in addition to measures of objective gain and output. Two examples of parental outcomes questionnaires are described below.

a) LittlEARS Auditory Questionnaire

The purpose of the LittlEARS Auditory Questionnaire is to assess the auditory behaviour of infants with permanent childhood hearing impairment who wear HAs or CIs (Coninx, et al. 2009; Tsaikpini, et al. 2004). It is recommended that administration of the LittlEARS questionnaire occurs at some point prior to HAF and at regular follow-up visits. The 35 questions in the LittlEARS questionnaire assess auditory development during the first two years of hearing in the real world and provides insight into receptive and semantic auditory behaviour as well as expressive-vocal behaviour. The questions are listed in an age-dependent order and are in a yes/no format. The total of all 'yes' answers provides a score that can be compared to average and minimum age-dependent values. These values are provided in one month age categories based on normative data (Coninx, et al. 2009). The LittlEARS questionnaire is designed to be answered by caregivers and is not affected by how it is administered (that is, under professional guidance or independently). The total 'yes' score is entered on the score sheet at the point where age and score meet. A child with a score in the shaded region is not meeting auditory milestones for their age. On the other hand, a child with a score above the shaded region is meeting auditory development milestones for their age.

When a minimum score of 27 or better is achieved, the child's performance is at a ceiling score. If ceiling is reached, the LittlEARS questionnaire should no longer be administered. Instead, the clinician can begin to administer the Parent's Evaluation of Aural/Oral Performance in Children (PEACH), either at that appointment or at the follow-up visit.

If a child is not wearing HAs but has an identified HL, the questionnaire can be useful for monitoring auditory development and tracking progress over time. In this case, the LittlEARS questionnaire should be administered at every follow-up visit.

b) Parent's Evaluation of Aural/Oral Performance in Children (PEACH) (Ching and Hill 2007).

The PEACH Rating Scale may be administered to children with normal hearing as well as to children with HL who may or may not wear HAs. The instructions ask caregivers to observe their child's behaviour in everyday life and rate their child's hearing performance over the previous week across a range of hearing and communication scenarios. The nature of the rating scale allows it to be answered by the caregiver during an appointment with guidance from the clinician. Administration of the PEACH should occur at regularly scheduled follow-up visits when the child has reached a score of 27 or greater on the LittlEARS Auditory Questionnaire and is 24 months of age and older. This prerequisite should ensure that the child's auditory skills are within the range of the PEACH. The overall score is summed, along with summed scores for the quiet and noise sub scales. Each sum (overall, quiet, noise) is converted to a percentage. The unshaded and shaded regions can be used as benchmarks against which to interpret individual scores. The current score ranges can also be used as benchmarks with which to compare individual scores. A child who scores well on the Quiet sub-scale but not in the Noise sub-scale would warrant further review of technology, or the use of an RM system in situations other than the classroom can be considered. These decisions should be made on a case-by-case basis and in conjunction with the needs of the child and family.

Conclusion

HAF in infants and children is a dynamic, lifelong process that demands careful consideration of candidacy, technology, verification and family involvement. Any type or degree of HL with the potential to hinder speech and language development qualifies a child for HAF, provided there are no contraindications for air conduction hearing devices. The preferred device for most infants and children is a behind-the-ear (BTE) HA with a silicon ear mould, paediatric ear hook, rechargeable or tamperproof battery, broadband amplification, noise reduction features and RM system compatibility. Verification of the fitting must include RECD values to confirm audibility of speech at comfortable and safe levels. These RECD values should be remeasured frequently and whenever new ear moulds are issued. Output at various input

levels must be verified using a calibrated speech signal, and MPO must be measured using a sweep tone. All children who are candidates for HAs are also candidates for RM systems, which should be verified in a HA test box. Outcome measures should include the use of validated questionnaires. Regular follow-up appointments are essential to monitor the stability or progression of HL, assess the impact of ear canal sound pressure levels on thresholds and HA performance and to replace or modify ear moulds as necessary. Crucially, the family should be involved at every stage of the HAF process to ensure optimal support and outcomes for the child.

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